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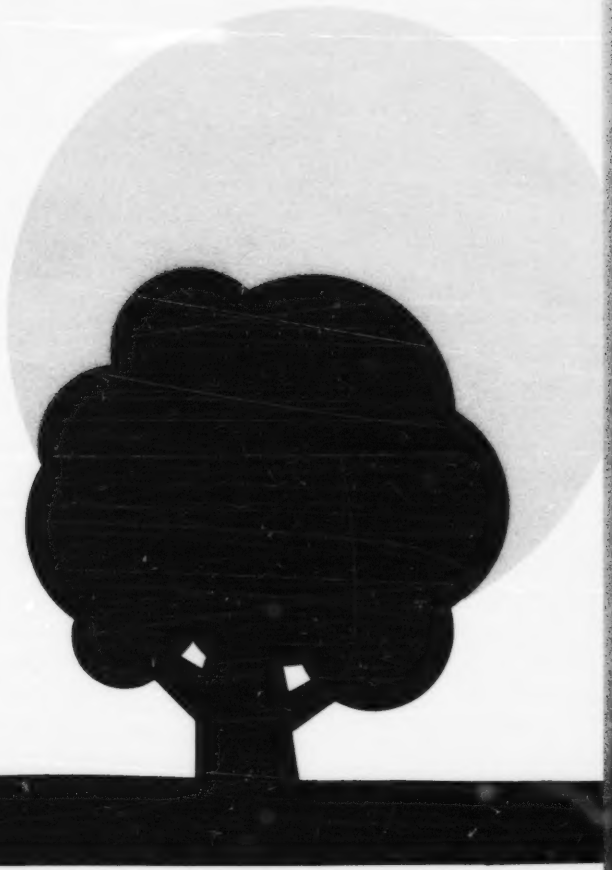

Energy, Mines and Resources Canada

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A WOOD-WASTE FUELLED, INDIRECTLY-FIRED GAS TURBINE COGENERATION PLANT FOR SAWMILL APPLICATIONS

Phase I:

Preliminary Engineering Design and Financial Evaluation

Renewable Energy Branch

PREPARED FOR:

Bioenergy Development Program
Renewable Energy Branch
Energy, Mines and Resources Canada
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ABSTRACT

The objective of this project is to develop a cost-effective system to generate electricity and dry kiln heat for sawmills, using an indirectly-fired gas turbine cycle. Sawmill residues burned in a fluidized bed combustor will heat clean air which will power the turbine before exhausting through a heat exchanger in the dry kiln. Phase I of the project provides a preliminary engineering design and indicates that the system generates very attractive financial returns under a variety of conditions.

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EXECUTIVE SUMMARY

Introduction

Although most sawmills generate more than enough wood waste to be potentially self-sufficient in both dry-kiln heat and electricity requirements, it is not generally economically viable to use conventional steam/electricity cogeneration systems at the sawmill scale of operation. As a result, Canadian sawmills are still large consumers of purchased fuels and electricity, spending $143 million on these energy sources during 1983.

The overall objective of this project, therefore, is to develop a cost-effective wood waste-fired power generation and lumber drying system for sawmill applications. The system proposed and evaluated in this project is a wood waste-fuelled, indirectly-fired gas turbine cogeneration plant. Research, design and development of the system has been planned to take place in a number of phases. Phase I consists of a preliminary engineering design and financial evaluation of the system and is the subject of this report.

Sawmill Energy Use

Sawmills and planing mills in British Columbia consumed almost 75 percent of purchased non-motive fuels and more than 60 percent of purchased electricity used by the industry on a national basis. At the same time, a large surplus of sawmill residues is available throughout most of the interior of the province. This analysis therefore focuses on British Columbia since it is the largest potential market for the sawmill cogeneration system.

In order to provide design parameters for the cogeneration system, operational characteristics were compiled for a "typical" sawmill in the interior of British Columbia. A mill scale of 50 million board feet of lumber output per annum,

virtually all of which is kiln-dried, has been adopted for this purpose. All clean solid wood residuals are assumed to be chipped for pulp fibre, while other solid wood residuals and bark are hogged. Approximately 25,000 oven-dried tonnes/annum of sawdust, shavings, bark, chip fines and solid wood residues will be available as fuel - more than enough to displace the 80,000 GJ of kiln fuel and 8,000 MWh of electricity typically consumed by a mill of this scale.

Design Concepts

A number of alternative design concepts were reviewed before arriving at the indirect-fired turbine concept selected for development in this project. The general concept involves the use of an open Brayton-cycle gas turbine as the prime mover to generate electrical power, while process heat for the dry-kiln is obtained by waste heat recovery from the turbine exhaust gas.

Air is first compressed in the gas turbine compressor and is then indirectly heated by a heat exchanger in a fluidized bed combustor burning wood waste. This heated and compressed air is then expanded in the turbine which drives a generator. In this way only pure air passes through the turbine, so that there is no possibility of corrosion or erosion by ash or other material found in the combustion products. The air leaving the turbine is still at a sufficiently high temperature so that it can provide all of the heat required for the lumber dry-kiln. This is done by routing the turbine exhaust air through a heat exchanger in the kiln. A kiln control box regulates the quantity of heat which is directed to the kiln heat exchanger, with the remainder being vented to atmosphere.

The proposed system has the following advantages over a conventional steam-based cogeneration system:

- no requirement for full-time licensed operators;
- greater simplicity of system - fewer components;
- reduced capital cost;
- reduced maintenance costs;
- no requirements for condenser cooling water.

System Design

Although the overall concept for the proposed system is novel, it is based entirely on proven components which do not require lengthy development efforts. A computer model was developed to select component sizes during the design phase, and then to predict the overall system performance once the design was fixed. Equipment suppliers were contacted to establish the availability and cost of system components.

The design criteria were that all of the dry-kiln heat requirements would be met by the cogeneration system, while at the same time most of the electrical requirements of the mill would be satisfied. The sawmill would still be connected to the electrical utility grid so that the cogeneration unit would not need to supply all of the mill's electrical requirements, while retaining a back-up source of power. In addition, surplus power could be sold into the grid during off-peak periods of sawmill operation.

To satisfy these requirements, a gas turbine/generator unit capable of producing 1340 kW of power (net output) and a fluidized bed combustor capable of providing 7.5 MW (27 GJ/hr) of indirectly-heated air were selected for the base case unit. In order to be able to easily determine the performance of many different versions of the proposed cogeneration system, a comprehensive computer model was developed. The model was used to optimize the system design and to predict the overall system performance under both full-load and part-load conditions.

Under full-load conditions the system provides the design heat input of 2930 kW (10 GJ/hr) to the lumber dry-kiln, and delivers a gross electrical output of 1490 kW. The fuel consumption under these conditions is 1.47 oven-dry tonnes per hour which, at a load factor of 80 percent, represents annual fuel requirements of about 45 percent of the total wood waste produced by a 50 million fbm sawmill. The overall thermal efficiency of the cogeneration system under these conditions is 55 percent.

Financial Analysis

The complete cogeneration system, including fuel handling and storage facilities, is expected to cost about $2.2 million on an installed basis, compared to about $3.6 million for a conventional steam cogeneration system. Operating costs are estimated at about $150,000 per annum - less than half those for a steam system. These projected capital and operating costs were balanced against savings in purchased fuel and electricity costs in an computerized financial feasibility model. This model calculated the after-tax internal rate of return on the project and examined the sensitivity of the internal rate of return to changes in a number of variables including base year energy prices, rate of energy price escalation, capital cost, debt/equity ratio, and financing rates.

The base case financial analysis incorporated the following assumptions:

Energy Prices:

Current natural gas and electricity prices in the interior of British Columbia are used to calculate the savings in purchased energy costs. Natural gas prices are assumed to remain constant in real terms over the first five years, escalating at two percent for the next five years, and at four percent thereafter. Electricity prices are held constant for the first five years, escalating at one percent per annum in real terms thereafter. No surplus power is assumed to be sold.

Revenue Assumptions:

Natural gas displaced	80,000 GJ @ $3.50/GJ
Electricity displaced	6,514 MWh @ $0.0264/kWh 1,340 kW @ $6.01/kW/month

Financial Assumptions:

Debt/equity ratio	60/40
Project life	20 years
Depreciation schedule	3 years (25%, 50%, 25%)
Corporate tax rate	46%
General inflation rate	4%
Loan rate	11%
Loan term	10 years

Under these assumptions the system provides an internal rate of return (IRR) of about 38 percent. A similar rate of return would be obtained with Quebec electricity prices, while in Ontario the system would show a 49 percent IRR. By comparison, a conventional steam system provides less than a 10 percent IRR.

The system is even more attractive in areas without natural gas service, yielding a 66 percent IRR for mills currently using liquified petroleum gases for kiln fuel. This increases to more than 118 percent for mills in remote locations with access to neither natural gas nor grid power.

The IRR is quite insensitive to changes in assumptions regarding future rates of energy price escalation or loan rates, and only moderately sensitive to changes in capital cost.

Conclusions

The results of this analysis indicate that the indirectly-fired gas turbine cogeneration system proposed in this study is both technically and financially feasible under a variety of conditions. On the basis of the excellent rates of return and strong expressions of interest by sawmill industry officials, the study team recommends that Phase II of the project should proceed as soon as possible. Phase II would be directed at achieving the following objectives:

- find industrial participants and a site for building a demonstration project;

- carry out a detailed engineering design and financial analysis for a specific site to the stage where a participation agreement can be put together for a demonstration project.

Successful achievement of these objectives will lead to the construction and operation of a demonstration cogeneration system during Phase III of the project.

SOMMAIRE - GESTION

Introduction

La plupart des scieries produisent suffisament de déchets de bois pour être virtuellement autosuffisantes en production d'électricité et de chaleur destinée aux séchoirs à bois. Cependant, il n'est généralement pas rentable d'utiliser des systèmes ordinaire de cogénération, vapeur-électricité, à l'échelle des opérations de scieries. Les scieries canadiennes sont donc encore d'importances consommatrices de combustible et d'électricité auxquels elles ont consacré 143 millions de dollars en 1983.

L'objectif global de ce projet est donc d'élaborer un système rentable qui recourt à la combustion des déchets de bois pour la production d'électricité et le séchage du bois dans les scieries. Le système proposé et évalué dans le cadre de ce projet est une usine de cogénération à turbine à gaz à chauffage indirect, qui brûle des déchets de bois. La recherche, la conception et l'élaboration de ce système a été planifiée en un certain nombre d'étapes. L'étape I est la conception préliminaire d'ingénierie et l'évaluation financière du système, et elle fait l'objet du présent rapport.

L'utilisation de l'énergie des scieries

Les scieries et les usines de planage de la Colombie-Britannique consomment environ 75 % des combustibles achetés pour d'autres fins que le transport et plus de 60 % de l'électricité achetée utilisée par cette industrie à l'échelle nationale. Simultanément, un important surplus de résidus de scieries est disponible dans toute la province. L'analyse porte donc principalement sur la Colombie-Britannique,étant donné qu'il s'agit du principal marché potentiel pour le système de cogénération des scieries.

Afin d'obtenir les paramètres de conception pour le système de cogénération, on a compilé les caractéristiques opérationnelles d'une scieries type de l'intérieur de la Colombie-Britannique. À cette fin, on a choisi une production repère de 50 millions de pieds-planches de bois de construction par année, qui est pratiquement toute séchée au four.

On suppose que tous les résidus solides propres de bois sont des copeaux destinés à la fabrication de pâte, alors que les autres matières résiduaires ligneuses et l'écorce sont broyées. Environ 25 000 tonnes anhydre par année de sciure de bois, de copeaux, d'écorce, de poussière de bois et de résidus de bois solides peuvent être utilisées comme combustible, ce qui équivaut à 80 000 GJ d'énergie utilisé par les séchoirs et 8 000 MWh d'électricité, consommés par une usine type de cette grandeur.

Concepts

Un certain nombre de concepts ont été examinés avant de s'arrêter sur le choix de la turbine à combustion indirecte dans le cadre de ce projet de développement. Ce concept est basé sur une turbine à gaz à cycle de Brayton ouvert utilisé comme force motrice pour produire de l'énergie électrique, alors que la chaleur destinée aux processus de séchage est obtenue par la récupération de la chaleur à l'échappement de la turbine à gaz.

L'air est d'abord comprimé dans le compresseur de la turbine à gaz et il est ensuite chauffé indirectement au moyen d'un échangeur de chaleur placé dans une chaudière à lit fluidifié et alimentée aux déchets de bois. Cet air chauffé et comprimé prend ensuite son expansion dans la turbine qui actionne un générateur. Ainsi, seul de l'air pur passe à travers la turbine, ce qui élimine la possibilité de corrosion ou

d'érosion par les cendres et par d'autres composés des produits de combustion. L'air qui quitte la turbine est encore à une température suffisamment élevée pour fournir la chaleur requise par un séchoir à bois. À cette fin, l'air d'échappement de la turbine est dirigé vers un échangeur de chaleur dans le séchoir. Le dispositif de contrôle du séchoir règle la quantité de chaleur dirigée vers l'échangeur de chaleur du séchoir, et le reste est évacué dans l'atmosphère.

Le système proposé présente les avantages suivants par rapport à un système ordinaire de cogénération à vapeur :

- il n'est pas nécessaire d'utiliser des opérateurs certifiés à plein temps;
- une plus grande simplicité du système, très peu d'éléments;
- coût d'immobilisation réduit
- frais d'entretien réduits
- il n'est pas nécessaire d'utiliser un condensateur pour le refroidissement de l'eau.

Conception du système

Bien que le concept général du système prévu soit nouveau, celui-ci est basé entièrement sur des éléments éprouvés qui ne nécessitent pas un long travail de développement. Un modèle informatisé a été élaboré pour choisir les dimensions des éléments dans la phase de la conception, et ensuite pour prévoir le rendement d'ensemble une fois la conception du système achevée. Les fournisseurs d'équipement ont été contactés pour déterminer la disponibilité et le coût des éléments du système.

D'après les critères de conception, toutes les exigences thermiques du séchoir à bois doivent être satisfaites par le système de cogénération, ainsi que la plus grande partie des besoins en électricité de la scierie. La scierie peut rester branchée au réseau électrique, de sorte que l'unité de cogénération n'ait pas à fournir l'entière demande en électricité de la scierie, tout en offrant une source d'énergie d'urgence. En outre, l'énergie électrique en surplus peut être vendue au réseau pendant les périodes creuses des opérations de la scierie.

Pour satisfaire à ces exigences, une unité de turbine à gaz/générateur capable de produire 1340 kW d'énergie (puissance nette) et une chaudière à lit fluidifié capable de fournir 7.5 MW (27 GJ/h) d'air chauffé indirectement ont été choisies comme éléments de base. Afin de pouvoir déterminer facilement le rendement des nombreuses versions possibles du système de cogénération proposés, un modèle informatique global a été élaboré. Ce modèle a été utilisé pour optimiser la conception du système et pour prévoir le rendement d'ensemble du système dans des conditions de pleine charge ou d'utilisation partielle.

Dans les conditions de pleine charge, le système fournit la pleine capacité nominale de chaleur de 2930 kW (10 GJ/h) au séchoir à bois et une production électrique brute de 1490 kW. Dans ces conditions, la consommation de combustible est de 1,47 tonnes anhydres de bois par heure ce qui, à un facteur de charge de 80 %, représente des exigences annuelles en combustible d'environ 45 % de la quantité totale de déchets produite par une scierie de 50 millions de pieds-planches. L'efficacité thermique globale du système de cogénération dans ces conditions est de 55 %.

Analyse financière

Le système de cogénération complet, y compris les installations de manipulation et de stockage, devrait coûter environ 2,2 millions de dollars une fois installé, contre environ 3,6 millions de dollars pour un système de cogénération à vapeur ordinaire. Les frais d'exploitation sont évalués à 150 000 $ par année, soit moins de la moitié de ceux du système à vapeur. Ces prévisions des coûts d'immobilisation et d'exploitation sont établies en fonction d'économies sur l'achat de combustible et d'électricité par un modèle informatisé de faisabilité financière. Ce modèle a calculé le taux de rendement interne après impôts du projet et a étudié la sensibilité du taux de rendement interne aux changements apportés à un certain nombre de variables, y compris les prix de base de l'énergie, le coût en capital, le ratio d'endettement et le taux de financement. L'analyse financière de base était fondée sur les hypothèses suivantes :

Prix de l'énergie:

Les prix actuels du gaz naturel et de l'électricité à l'intérieur de la Colombie-Britannique sont utilisés pour calculer les économies sur les coûts de l'énergie achetée. On suppose que les prix du gaz naturel sont constants pour les cinq premières années, puis augmentent à raison de 2 % pour cinq autres années, et de 4 % par la suite. Les prix de l'électricité sont constants pour les cinq premières années, puis augmentent à un rythme de 1 % par année en valeur réelle. On suppose qu'aucune énergie excédentaire n'est vendue.

Hypothèses concernant les revenus :

Gaz naturel remplacé	80 000 GJ à $ 3 50/GJ
Électricité remplacée	6 514 MWh à $0 0264/kWh
	1 340 kW à $6 01/kW/mois

Hypothèses financières :

Ratio d'endettement	60/40
Durée prévue du projet	20 ans
Amortissement	(3 années : 25 %, 50 %, 25 %)
Impôt sur les sociétés	46 %
Taux général d'inflation	4 %
Taux d'intérêt du prêt	11 %
Durée du prêt	10 ans

Selon ces hypothèses, le système produit un taux de rendement interne (TRI) d'environ 38 %. Un taux de rendement semblable serait obtenu avec les prix de l'électricité au Québec, alors qu'en Ontario, ce système produirait un TRI de 49 %. Cependant, un système à vapeur ordinaire donne un TRI inférieur à 1 %.

Ce système est encore plus intéressant dans les endroits sans gaz naturel, donnant un TRI de 66 % dans les scieries qui utilisent du gaz liquéfié pour alimenter le séchoir en combustible. Cette valeur passe à plus de 118 % dans le cas des scieries éloignées qui ne sont desservies ni par des réseaux de gaz naturel ou d'électricité.

Le TRI est très peu sensible aux modifications dans l'hypothèse d'éventuelles augmentations des prix de l'énergie ou des taux d'intérêt sur les prêts. Il est modérément sensible aux modifications de coût d'immobilisation.

Conclusions

Les résultats de la présente analyse indiquent que le système de cogénération à turbine à gaz chauffée indirectement proposé dans la présente étude est techniquement et financièrement faisable et ceci sous une variété de conditions différentes. Compte tenu des excellents rendements et de l'intérêt considérable suscité par ce projet dans l'industrie des scieries, l'équipe de l'étude recommande que l'étape II du projet soit entreprise aussitôt que possible. Les buts visés de cette seconde étape devraient être les suivants :

- trouver des participants industriels et un emplacement pour construire un projet de démonstration;

- préparer une analyse financière et un projet d'ingénierie détaillés pour un emplacement particulier jusqu'à l'étape où un accord de participation peut être obtenu pour un projet de démonstration.

Ces objectifs réalisés, on pourra passer à l'étape III du projet, soit la construction d'un système de cogénération en vue d'en démontrer la mise en exploitation.

1.0 INTRODUCTION

1.1 Background

Sawmills produce large quantities of wood waste in the form of sawdust, shavings, bark and other wood waste which cannot be converted into lumber or pulp chips. At the same time, as detailed in Section 2, they have significant demands for electrical power and for process heat to dry the lumber in dry-kilns. Although most sawmills generate more than enough wood waste to be self-sufficent in both dry-kiln heat and electricity requirements, it is not generally viable to use conventional steam/electricity cogeneration systems at the sawmill scale of operation. Wood waste-fuelled systems providing process heat for dry-kilns are in fairly common usage but, generally speaking, no cost-effective systems have been available to date for the cogeneration of both heat and electricity, at least under present or foreseeable fuel and electricity prices.

The situation is particularly critical for sawmills located in remote regions. These mills may not have ready access to utility electrical power or to natural gas, which is the preferred fuel for drying lumber. In these situations they face the expense of producing their own power using diesel generating sets, and using oil or propane as fuel for drying the lumber.

1.2 Objectives

In view of this situation, therefore, the overall objective of this project is to develop a cost-effective wood waste-fired power generation and lumber drying system for sawmill applications. The system chosen for development in this project, for reasons explained in Section 3.0, is a wood waste-fuelled, indirectly-fired gas turbine cogeneration plant.

Research, design and development of the cogeneration system has been planned in several phases. Phase I of the project, which consists of an engineering and financial feasibility study, is the subject of this report. During this phase various

technical options were evaluated and a preliminary engineering design, complete with a detailed heat balance, was prepared for the most favourable option. A financial analysis of the system was then prepared to calculate the anticipated internal rate of return under a variety of energy price and capital cost scenarios.

The following tasks were undertaken during Phase I of the project:

(i) Calculation of an overall energy and materials balance for a typical sawmill producing 50 million board feet of lumber per year.

(ii) Selection and sizing of major equipment components, based on the sawmill energy and materials balance.

(iii) Preliminary design of the best alternative, including heat and material balances.

(iv) Calculation of overall system performance under both full-load and part-load operation.

(v) Cost analysis of the complete cogeneration system.

(vi) Financial feasibility analysis of the system.

(vii) Preparation of a final report, including recommendations for Phase II.

As currently proposed, Phase II has the following objectives:

(i) To find industrial participants and a site for a demonstration project.

(ii) To carry out a detailed engineering design and financial analysis for a specific site to the stage where a participation agreement can be put together for a demonstration project.

successful achievement of these objectives will lead to the construction and operation of a demonstration cogeneration system during Phase III of the project.

1.3 Method

Purchased sawmill energy use during 1983 was obtained from Statistics Canada data to identify the quantities and types of fuels currently used and the largest potential provincial markets for the cogeneration system considered herein. Sawmill energy use at the individual mill level was then obtained from a review of published sources, along with a materials balance which indicates the quantities of wood wastes available for energy conversion for a representative mill scale of 50 million board feet per annum. Bachrich Consulting Ltd. provided advice as to the quantity and quality of heat required for lumber drying. This data was used to establish sizing and operational parame ters for the cogeneration system.

A number of alternative system design concepts were reviewed by R.L. Evans & Associates Ltd. before arriving at the concept selected for development in this project. A computer model was developed to select component sizes during the design phase, and then to predict the overall system performance once the design was fixed. Equipment suppliers were contacted to establish the availablility and cost of system components.

Projected capital and operating costs of the system were then balanced against savings in purchased fuel and electricity costs in a financial feasibility model. This model calculated the after-tax internal rate of return on the project and examined the sensitivity of the internal rate of return to changes in a number of variables including base year energy prices, rate of energy price escalation, capital cost, debt/equity ratio, and financing rate.

Based on the study team's assessment of the technical and financial feasibility of the cogeneration system considered herein, a number of recommendations were made concerning further development of the system.

2.0 SAWMILL ENERGY USE

This section examines sawmill energy use at both the macro and micro levels. At the macro level, an overview is presented of the quantities of energy consumed by sawmills in Canada, along with the associated energy cost. This data provides an indication of the magnitude of the potential market for a financially viable sawmill-scale cogeneration system. At the micro level, an energy and materials balance is provided for a representative sawmill in order to establish design parameters for the cogeneration system considered in this project.

2.1 Overview of Energy Use in Canadian Sawmills

In spite of greatly increased use of wood wastes as a kiln drying heat source, Canadian sawmills are still one of the largest industrial users of fossil fuels, while electricity use per unit of output is continuing to increase through further mechanization. Purchased fuel and electricity use in Canadian sawmills and planing mills during 1983 is summarized in Table 2-1. Motive fuels (gasoline and diesel fuel) are excluded as they are not directly substitutable by wood wastes.

As shown in Table 2-1, Canadian sawmills consumed in excess of $140 million worth of purchased non-motive fuels and electricity during 1983. This level of energy use was surpassed in only five other 3-digit manufacturing industry groups on a national basis during the same year.

Mills in British Columbia alone accounted for almost 75 percent of total Canadian sawmill fuel use and more than 60 percent of purchased electricity consumption. This large energy demand, combined with the continuing surplus of sawmill residues throughout the interior of the province, makes British Columbia a prime market for a financially viable sawmill-scale cogeneration system. This analysis therefore focuses on British Columbia as a potential market for the cogeneration system, although the financial analysis (Section 5.0) also examines the feasibility of the system in Ontario and Quebec locations.

TABLE 2-1: PURCHASED ENERGY USE IN CANADIAN SAWMILLS AND PLANING MILLS, 1983

	British Columbia	Quebec	Ontario	All Canada	
	----------Terajoules*----------				Million $
Purchased Fuels (non-motive)					
Natural Gas	8,482.5	15.2	949.3	10,711.3	$32.8
Light Fuel Oil	77.6	171.9	190.9	461.0	$3.7
Heavy Fuel Oil	23.5	341.9	37.3	529.6	$2.7
LPG	520.7	25.4	90.4	644.9	$5.2
Total Fuels	9,104.3	554.4	1,267.9	12,346.8	$44.3
% of All Canada	74%	4%	10%	100%	
Purchased Electricity					
Gwh	1592.6	557.9	223.9	2585.4	$98.7
Terajoules	5,733.4	2,008.4	806.0	9,307.4	
% of All Canada	62%	22%	9%	100%	
TOTAL ENERGY	14,837.7	2,562.8	2,073.9	21,654.3	$143.0

Source: Statistics Canada, Catalogue 57-208 Annual, Consumption of purchased fuel and electricity by the manufacturing, mining, logging and electric power industries, 1983.

*Converted from natural units on the basis of the following Statistics Canada factors (Catalogue 57-003):

	TJ
Natural Gas	37.97 /gigalitre
Light Fuel Oil	38.68 /megalitre
Heavy Fuel Oil	41.73 /megalitre
LPG	27.12 /megalitre
Purchased Electricity	3.60 /gigawatt hour

2.2 Sawmill Energy and Materials Balance

2.2.1 Representative Sawmill Scale and Operational Characteristics

While there are many sawmills in Canada with annual capacities in excess of 100 million board feet (236 thousand cubic metres, nominal basis), the average capacity is considerably less, particularly in remote areas where the cogeneration system would be most applicable. For the purposes of this analysis, a sawmill with an annual capacity of 50 million board feet (118 thousand cubic metres) has been selected as a representative scale of mill.

It is also necessary to specify the operational characteristics of the sawmill considered in this study, as the energy and materials balances vary substantially among different mill configurations and regions. The balances in this section are representative of an average British Columbia interior mill which has the following characteristics:

- white spruce or lodgepole pine are the dominant species cut;
- virtually all lumber output is kiln-dried;
- all clean solid wood residuals are chipped for pulp fibre;
- other wood residuals and bark are hogged;
- sawmill cuts 480 shifts, or 3840 hours per year;
- dry-kilns operate 8400 hours per year.

2.2.2 Materials and Energy Balance

Table 2-2 shows the materials and energy balance for a typical B.C. interior sawmill. The product yield percentages are based on "Conversion Factors for the Forest Products Industry in Western Canada" (Nielson, Dobie, and Wright, 1985), with some minor adjustments to reflect increases in lumber recovery factors that have occurred since the surveys upon which the foregoing source was based

TABLE 2-2: MATERIALS AND ENERGY BALANCE FOR INTERIOR B.C. SAWMILL

Nominal Output: 50 Million fbm (118,000 m3)
@480 shifts/year
(surfaced and kiln-dried spruce lumber)

MATERIALS BALANCE	% log volume	m3 SWE
Finished lumber	40%	80,000
Pulp chips	38%	76,000
Sawdust	9%	18,000
Shavings	8%	16,000
Other*	5%	10,000
Total wood input	100%	200,000
Bark	10%	20,000

*Chip fines and solid wood residues

WOOD WASTE AVAILABILITY AND CHARACTERISTICS

Component	m3 SWE	Oven-dry Density (kg/m3)	Weight (ODT)	Higher Heating Value (GJ/ODT)	Moisture Content (wet basis)
Sawdust and other	28,000	360	10,080	19.8	40%
Shavings	16,000	360	5,760	19.8	15%
Bark	20,000	449	8,980	20.3	50%
Total	64,000		24,820		

ENERGY REQUIREMENTS

Electricity	160 kwh/mfbm	8,000	Mwh/Annum
Kiln Fuel**	1.6 GJ/mfbm	80	TJ/Annum

** Natural gas or LPG

NOTES:

SWE - Solid Wood Equivalent

Nominal Output - is higher than the actual output of finished lumber, as it is based on the nominal, rather than actual, dimensions of the planed and kiln-dried lumber.

were undertaken. Assuming that all chippable by-product material is used as pulp fibre, almost 25 thousand oven-dried tonnes (Odt) of sawdust, shavings, bark, chip fines and solid wood residues will be available as fuel. The higher heating value and moisture content of each of these waste components are shown in Table 2-1.

On the demand side of the equation, sawmills in the B.C. interior typically use almost 160 kwh of electricity and 1.6 GJ of natural gas (or LPG) per thousand board (Mfbm) of surfaced, dry lumber, based on a survey of mills by the Council of Forest Industries. This coefficient corresponds to a moisture content in the order of 50 to 60 percent, dry basis. In fact, it is not uncommon for some sawmills in Canada to dry lumber with initial moisture contents of up to 100 percent, doubling the kiln drying fuel requirement. This analysis is therefore conservative in terms of its assumptions concerning the physical quantity (and therefore, also the dollar value) of natural gas that would be saved by the cogeneration system.

The electrical energy use coefficent may, in practice, vary widely from mill to mill, depending upon the type of equipment used in each mill. Dry kilns are estimated to consume about 20 percent of the total electrical consumption of 160 kWh/Mfbm. This is an almost constant load, as the kilns are estimated to operate 8400 hours per annum, unlike the sawmill which operates an average of 3840 hours annually.

The quantity of wood wastes available is more than sufficient to displace the 80,000 GJ of kiln fuel and 8,000 MWh of electricity typically consumed by a mill of this scale.

3.0 DESIGN CONCEPTS

This section briefly discusses a number of alternative cogeneration system concepts, along with the concept selected for development in this project. Advantages of the proposed system over conventional steam power plants are summarized.

3.1 Alternative Concepts

The best-known solution to the provision of both electricity and process heat from wood waste is a conventional Rankine cycle steam power plant. This type of plant uses an extraction-condensing steam turbine to generate electrical power and to provide steam for kiln heating. These plants are usually not economical, however, on the relatively small scale of most sawmill applications. Another factor which lessens the desirability of a conventional steam power plant is the requirement in most jurisdictions for licensed steam plant operators to be present at all times. This requirement can substantially increase the operating cost for a typical sawmill, so steam power plants are almost never considered for modern sawmill applications.

A partial solution is to use wood waste to provide the kiln heat requirements only, while still purchasing electricity from the local utility. There are a number of specially-designed wood waste burners now on the market which are being used in this way. These units only utilize a small fraction of the total wood residue production, however, and all of the mill electrical requirements must still be supplied from an outside source. This may or may not be an attractive option for a sawmill operator, depending on the local availability and cost of purchased electricity.

At one time the development of a gasifier which would convert wood waste into producer gas appeared to be a very promising option. The concept was to utilize relatively inexpensive gasifiers to produce a low heating value gas which could then be used as a fuel both for kiln heating and for the generation of electrical

power from internal combustion engines. A similar concept was used in Europe during the second world war to provide producer gas where there was a shortage of more conventional fuels. In the 1970's there was a considerable development effort in Canada aimed at producing a gasifier, essentially scaled up from the war-time units, which would use wood waste at a sawmill. A demonstration unit was built and installed at Ainsworth Lumber in B.C., but had to be abandoned after a great deal of development work failed to produce a reliable unit.

The main problems with the gasifier evidently centred around the difficulty of providing reliable ash-removal and in gas clean-up. The low heating value gas produced from wood waste contains substantial quantities of tar and condensible vapours which are not compatible with the operation of internal combustion engines. Although in principle gas clean-up equipment could be installed, the added cost and complexity of such systems soon makes the unit impractical for sawmill operation. It appears, then, that the gasifier option is not suitable for use in sawmills, and developments in this area have largely been dropped.

3.2 The Proposed Concept

For this study a novel concept has been proposed in which an open Brayton cycle gas turbine engine is used as the prime mover to generate electrical power, while process heat for the dry-kiln is obtained by waste-heat recovery from the turbine exhaust gas. Gas turbines are normally fuelled with natural gas or distillate fuel which means that they are usually utilized only for stand-by power generation because of the high operating costs. There have been some attempts in the past to develop gas turbine units which were directly fired by wood waste combustion products, but these have been unsuccessful due to the corrosion and erosion effects of ash and salt compounds on turbine blading. Even after considerable efforts to develop granular bed filters and other hot gas clean-up devices, no reliable systems have been developed to utilize wood waste or other solid fuels in a directly-fired gas turbine cycle.

The concept proposed here is illustrated schematically by the cycle diagram shown in Figure 1. Air is first compressed in the gas turbine compressor and is

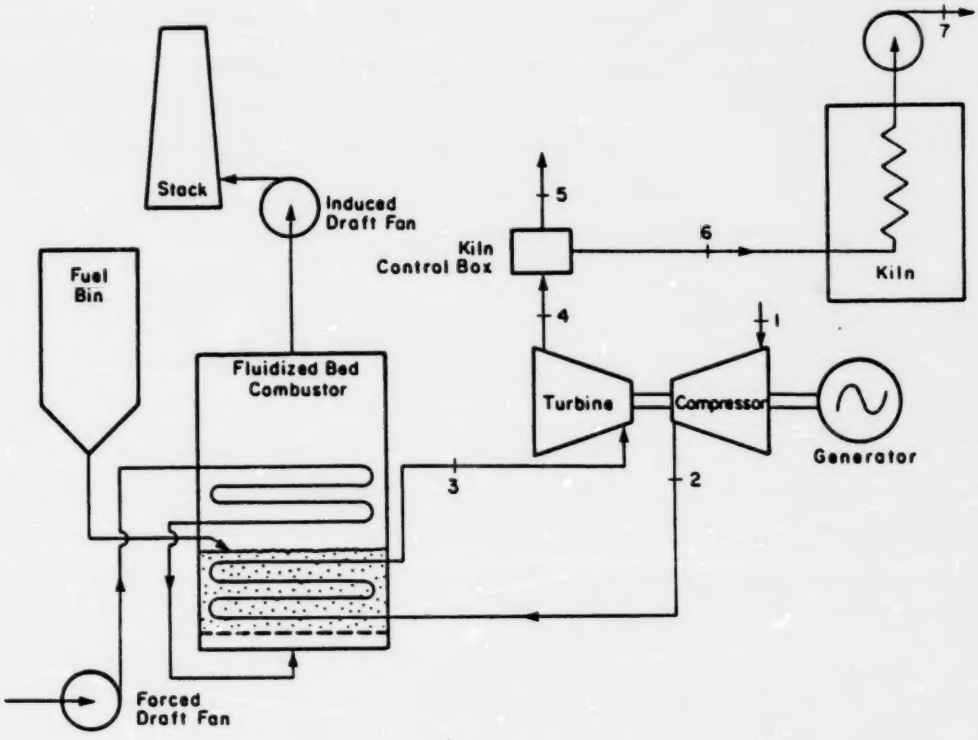

FIGURE 1: THE INDIRECTLY-FIRED GAS TURBINE COGENERATION SYSTEM

then indirectly heated by a heat exchanger in a fluidized bed combustor burning wood waste. This heated and compressed air is then expanded in the turbine which drives a generator. In this way only pure air passes through the turbine, so that there is no possibility of corrosion or erosion by ash or other material found in the combustion products. The air leaving the turbine is still at a sufficiently high temperature so that it can provide all of the heat required for the lumber dry-kiln. This is done by routing the turbine exhaust air through a heat exchanger in the dry-kiln which is used to supply all of the heat required to maintain the kiln at an appropriate temperature. The kiln control box regulates the quantity of heat which is directed to the kiln heat exchanger, with the remainder being vented to atmosphere.

Although the overall concept proposed here is novel, it is based entirely on proven components which do not require lengthy development efforts. Because of the indirectly heated air used in this cycle, the gas turbine inlet temperature is reduced to about 750°C from a normal value of 900°C when distillate fuel or natural gas is used. This reduction in turbine inlet temperature results in a de-rating of the turbine which, in simple cycle operation, would greatly reduce the cycle efficiency. In the cogeneration system proposed here, however, the overall thermal efficiency remains high since exhaust energy which would otherwise be wasted is utilized to provide kiln heat. Also, since there is more than enough fuel available free of charge, there is no penalty incurred by de-rating the gas turbine power output. The emphasis, then, in the proposed concept is on simplicity of the overall design rather than on high efficiency.

The advantages of the proposed system compared to a conventional steam-based system may be summarized as follows:

(i) No requirement for full-time licenced operators.
(ii) Greater simplicity of system - fewer components.
(iii) Reduced capital cost.
(iv) Reduced maintenance costs.
(v) No requirement for condenser cooling water.

4.0 SYSTEM DESIGN

The emphasis on design of the overall system was to utilize proven components as far as possible. This was done to ensure that the development time for the system would be as short as possible. The design criteria were that all of the dry-kiln heat requirements would be met, while at the same time most of the electrical requirements of the mill would be satisfied by the cogeneration system. The sawmill would still be connected to the electrical utility grid, however, so that the cogeneration unit would not necessarily have to supply 100 percent of the mill's electrical requirements. This also provides a back-up capability from the utility in the event that the cogeneration system is out of service for any reason. In addition, it would permit the system to supply surplus power to the grid during off-peak periods of sawmill operation, thereby generating additional revenue.

4.1 Equipment Selection

The two key components in the system design are the gas turbine and the fluidized bed combustor unit. In selecting the gas turbine several factors were considered. The unit size of the turbine should be such that it would be capable of producing a power output of approximately 2 MW at rated design conditions. The turbine would be de-rated in the cogeneration scheme, due to the lower turbine inlet temperature, and would then be capable of producing about 1340 KW (net output). This power output level would be capable of supplying most of the electrical requirements for a 50 million fbm per year sawmill.

Another important consideration in selection of the gas turbine was that it should have an external combustor. This is important, since in the indirectly-fired cogeneration system the combustor would be replaced by ducts used to convey compressor delivery air to the fluidized bed combustor and to deliver heated air back to the turbine. A final consideration was that the gas turbine should be manufactured in Canada, or be available from a Canadian supplier. The unit selected was a Kawasaki model M1T, distributed in North America by

Cullen Detroit Diesel Allison Ltd. of Vancouver. This unit has a nominal output of 2 MW at rated conditions on distillate fuel, with a turbine inlet temperature of 900°C. The unit is actually comprised of two individual gas turbine units connected to a generator by a gear box, and each turbine unit has its own external combustion chamber. These external combustor chambers can readily be removed and replaced by the necessary ductwork to connect the unit to the fluidized bed combustor. A generator package incorporating only one gas turbine unit is also available with a nominal power rating of 1 MW. This unit could also be used for a small-scale demonstration unit. Although the complete sawmill electrical requirements would not be met by this single unit, it could still be used to demonstrate the technology.

In selecting a wood waste fuelled combustion system, emphasis was also placed on the availability of proven technology. In this case there appeared to be very few manufacturers who had experience with using fluidized bed combustors to produce heated air. The only manufacturer who had operational experience using a fluidized bed combustor to indirectly heat air was the Fluidyne Corporation of Minneapolis. Fluidyne is a large engineering company which is involved in many aspects of high-technology development, particularly those related to fluid flow and energy systems. For several years Fluidyne has operated a fluidized bed combustion unit capable of providing sufficient quantities of heated air for the cogeneration system. A Fluidyne unit with a net heating capacity of 7.5 MW (27 GJ/hr.) was therefore selected for the base case design for this study. An alternative unit of 3.75 MW (13.5 GJ/hr.) net heating capacity was also considered for the case using the single M1A gas turbine.

4.2 The Computer Model

In order to be able to easily determine the performance of many different versions of the proposed cogeneration system, a comprehensive computer model was developed. The model was then used to optimize the system design and to predict the overall system performance under both full-load and part-load conditions. The model incorporated a number of sub-models to calculate the thermodynamic properties at each stage of the process, such as the fluidized bed

combustor and the gas turbine unit. Input data for the gas turbine unit was taken from the manufacturer's specifications, where available. For data not available from the manufacturer, such as compressor and turbine efficiency, the gas turbine sub-model was run using various assumptions until the manufacturer's quoted performance was obtained under full-load conditions. These values were then used in the model for all of the subsequent calculations. The model was programmed in Pascal using the Turbo-Pascal compiler, suitable for running on an IBM AT computer, or equivalent.

For the sub-model of the fluidized bed combustor unit, data from the manufacturer was also used, where available. For input data not immediately available from the manufacturer, information from the open literature was used. For example, correlations for the heat transfer coefficient for the in-bed heat exchanger were obtained from the paper by Evans and Anastasiou (1985). The input parameters required for determination of the in-bed heat transfer coefficient included the mean particle size, the superficial fluidizing velocity, and the bed temperature.

Since the selection of the surface area required for the in-bed heat exchanger is one of the key parameters for such a design, a sensitivity analysis was also conducted to examine the effect on the required heat exchanger area of varying both the in-bed heat transfer coefficient and the heat exchanger tubing internal heat transfer coefficient. The results of this sensitivity analysis are shown in Figures 2 and 3.

Figure 2 shows the required bed heat exchanger area as a function of the in-bed heat transfer coefficient, with the internal heat exchanger coefficient as a parameter. Figure 3 shows the data re-plotted with the required heat exchanger area as a function of the internal heat transfer coefficient, with the in-bed heat transfer coefficient as a paramenter. These calculations indicate that the heat exchanger area is not very sensitive to the two heat transfer coefficients, as long as the in-bed coefficient is above the 300 $W/m^2\ ^oC$ and the internal coefficient is above about 100 $W/m^2\ ^oC$. The design values determined from correlations found in the literature were 118 $W/m^2\ ^oC$ for the internal coefficient, and 367 $W/m^2\ ^oC$ for the in-bed heat transfer coefficient.

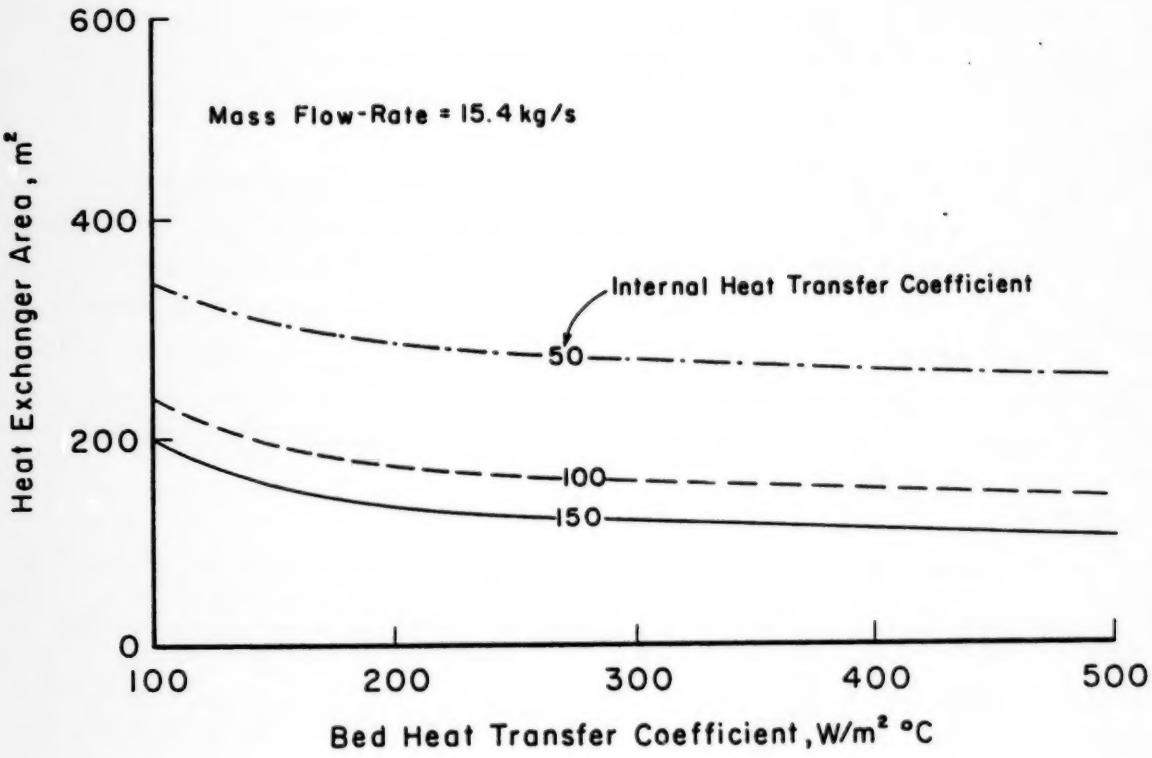

FIGURE 2: HEAT EXCHANGER AREA VS. BED HEAT TRANSFER COEFFICIENT

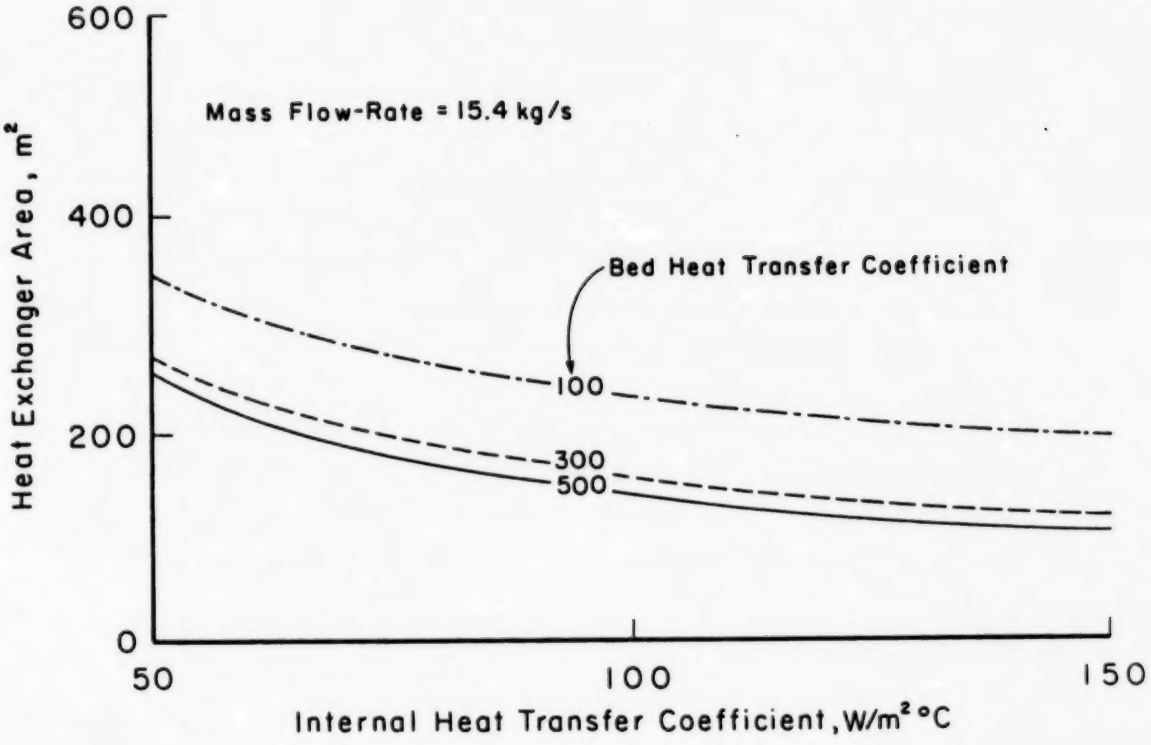

FIGURE 3: HEAT EXCHANGER AREA VS. INTERNAL HEAT TRANSFER COEFFICIENT

Finally, Figure 4 shows the dependence of the required heat exchanger area on the compressor delivery air mass-flow rate. These calculations resulted in a required heat exchanger area of 263 m^2 for the base case unit providing a net heating capacity of 7.5 MW (27 GJ/hr.) with an air mass-flow rate of 15.4 Kg/s.

4.3 Computer Model Results

As mentioned previously, the computer model was used both to select component sizes during the design phase, and then to predict the overall system performance once the design was fixed. In the design stage the model was particularly helpful in selecting the heat exchanger area and the net heating capacity required for the fluidized bed combustor, seen in the previous section. The design conditions chosen for analysis are summarized in Table 4-1. The base case is the double unit, which refers to the M1T gas turbine unit with two turbines geared to a single generator to provide a nominal rating of 2MW. Table 4-1 also gives the conditions for the alternative case considered using the M1A single gas turbine unit with a nominal rating of 1 MW. The following sections summarize the results of the performance calculations which were made using the computer model to predict both full-load and part-load performance.

4.3.1 Full-Load Results

The full-load performance of the base-case cogeneration system is summarized in Table 4-2 and Figure 5. The base case is for the system incorporating the double turbine M1T gas turbine unit and the fluidized bed capable of providing 7.5 MW of indirectly heated air. Figure 5 is a heat balance diagram indicating the mass-flow rates and temperatures at various points in the cycle. Under full-load conditions the system provides the design heat input of 2930 kW (10.5 GJ/hr) to the lumber dry kiln, and delivers a gross electrical output of 1490 kW (1340 kW net). The fuel consumption under these conditions is 1.47 oven-dry tonnes (ODT) per hour, which, at a load factor of 80 percent, represents annual fuel requirements of about 45 percent of the total wood waste produced by a 50 million fbm sawmill (see table 2-2). The overall thermal efficiency of the cogeneration system under these conditions is 55 percent.

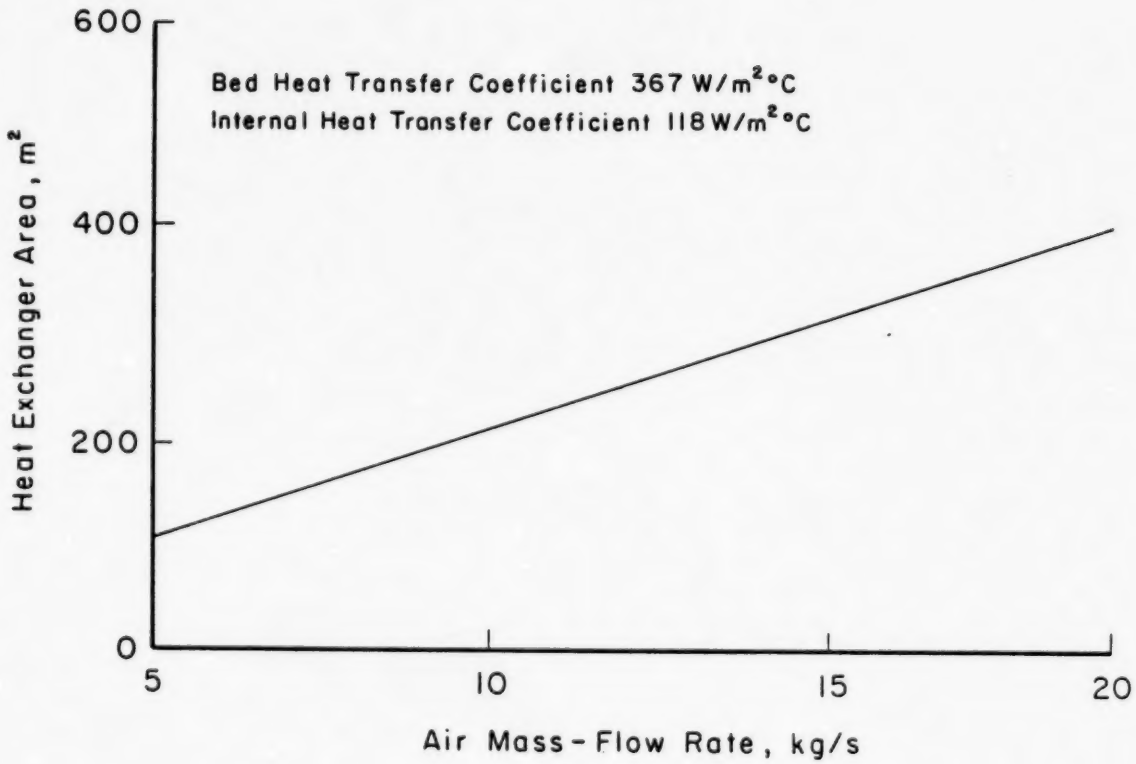

FIGURE 4: HEAT EXCHANGER AREA VS. AIR MASS-FLOW RATE

TABLE 4-1: DESIGN CONDITIONS FOR GAS TURBINE COGENERATION SYSTEM

	Single Unit	Double Unit
Turbine Air Mass Flow Rate	7.7 kg/s	15.4 kg/s
Compressor Efficiency	78%	78%
Turbine Efficiency	86%	86%
Turbine Pressure Ratio	8:1	8:1
Bed Heat Exchanger Area	132 m^2	263 m^2
Bed Heat Exchanger Effectiveness	74%	74%
Kiln Heat Exchanger Area	390 m^2	650 m^2
Fuel Heating Value	20 MJ/kg	20 MJ/kg

SOURCE: R.L. Evans and Associates Ltd.

TABLE 4-2: FULL-LOAD OPERATIONAL PARAMETERS

	Single Unit	Double Unit
Fluidized Bed Temperature	900°C	900°C
Turbine Inlet Temperature	750°C	750°C
Fluidized Bed Heat Transfer	3.75 MW	7.5MW
Gross Power Output	745 kW	1490 kW
Kiln Heat Input	1640 kW	2930 kW
Kiln Air Mass Flow Rate	7.7 kg/s	15.4 kg/s
Kiln Air Supply Temperature	385°C	385°C
Fuel Consumption	0.74 ODT/hr	1.47 ODT/hr
Overall Thermal Efficiency	59%	55%

TABLE 4-3: PART-LOAD OPERATIONAL PARAMETERS - DOUBLE UNIT

	100% Electrical Load 50% Kiln Heat Load	50% Electrical Load 50% Kiln Heat Load
Fluidized Bed Temperature	900°C	726°C
Turbine Inlet Temperature	750°C	627°C
Fluidized Bed Heat Transfer	7.5MW	5.2MW
Gross Power Output	1490 kW	745 kW
Kiln Heat Input	1465 kW	1465 kW
Kiln Air Mass Flow Rate	6.8 kg/s	11.8 kg/s
Kiln Air Supply Temperature	385°C	300°C
Fuel Consumption	1.47 ODT/hr	1.04 ODT/hr
Overall Thermal Efficiency	37%	39%

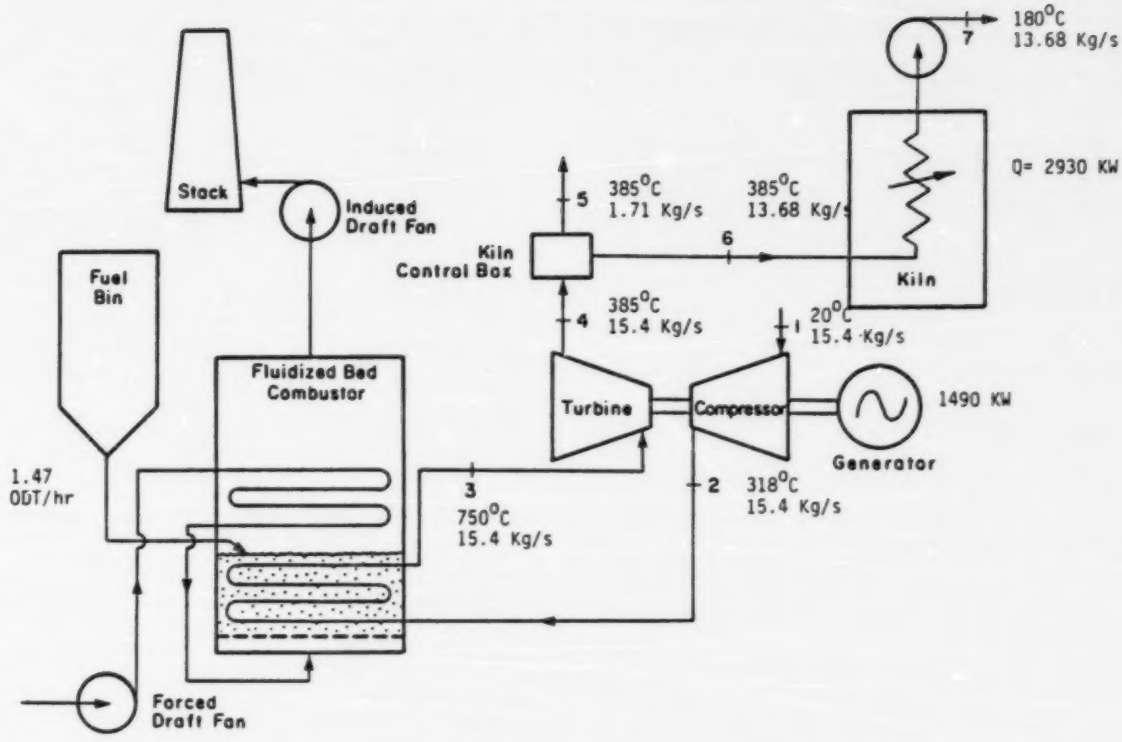

FIGURE 5: FULL-LOAD HEAT BALANCE DIAGRAM FOR DOUBLE TURBINE (M1T) UNIT

The full-load performance for the alternate case with the single turbine M1A gas turbine unit is summarized in Table 4-2 and Figure 6. For this case the fluidized bed combustor has an air heating capacity of 3.75 MW (13.5 GJ/hr). Under these conditions the cogeneration unit generates 745 kW of gross electrical power and provides a maximum of 1640 kW (5.9 GJ/hr) to the dry kiln. The reduced kiln heat input is due to the reduced turbine air mass-flow with the single turbine M1A unit. This reduced kiln heat input could still be used for a demonstration system, but it would result in a longer drying schedule than for the case with the full 2930 kW (10.5 GJ/hr) available. An alternative solution with the single turbine unit would be to utilize a larger fluidized bed combustor together with a secondary heat exchanger which would provide a stream of heated air directly to the kiln without first being expanded in the gas turbine unit. The overall system thermal efficiency is 59 percent for this case.

4.3.2 Part-Load Results

For the base case system design, two part-load operating points were examined with the computer model to provide an indication of the system performance when less than the full design power output or kiln heat input is required. The first case considered is for 100 percent electrical load and 50 percent kiln heat requirements. The results for operation under these conditions are summarized in Table 4-3 and Figure 7. The reduced kiln heat input is simply achieved through by-passing more of the turbine exit air to exhaust through the kiln control box, rather than to the kiln. This results in 1465 kW (5.3 GJ/hr) being delivered to the kiln while the power output and fuel consumption remains the same as for the full-load case. The overall thermal efficiency for the complete cogeneration system under these conditions is 37 percent.

The final part-load case considered was for 50 percent electrical load and 50 percent kiln heat requirements. The results for this operating regime are also shown in Table 4-3, and the heat balance diagram of Figure 8. In this case the reduced electrical power output is achieved by a reduction in the turbine inlet temperature which is, in turn, achieved by a reduction in the fluidized combustor

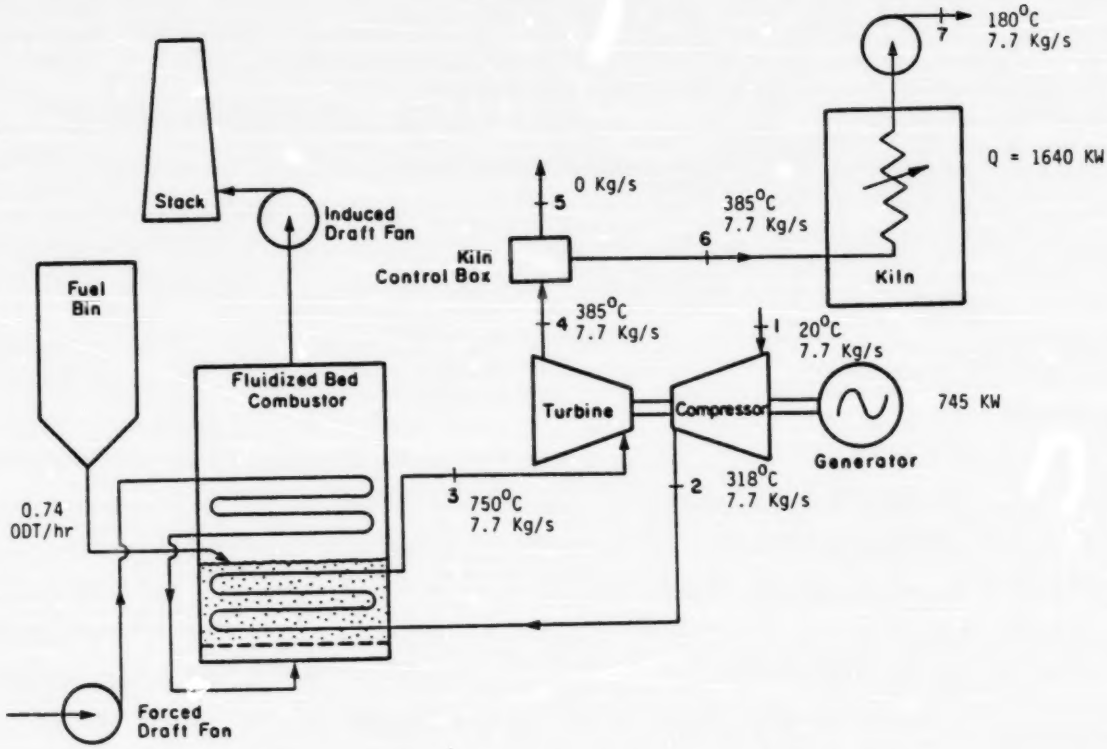

FIGURE 6: FULL-LOAD HEAT BALANCE DIAGRAM
FOR SINGLE TURBINE (M1A) UNIT

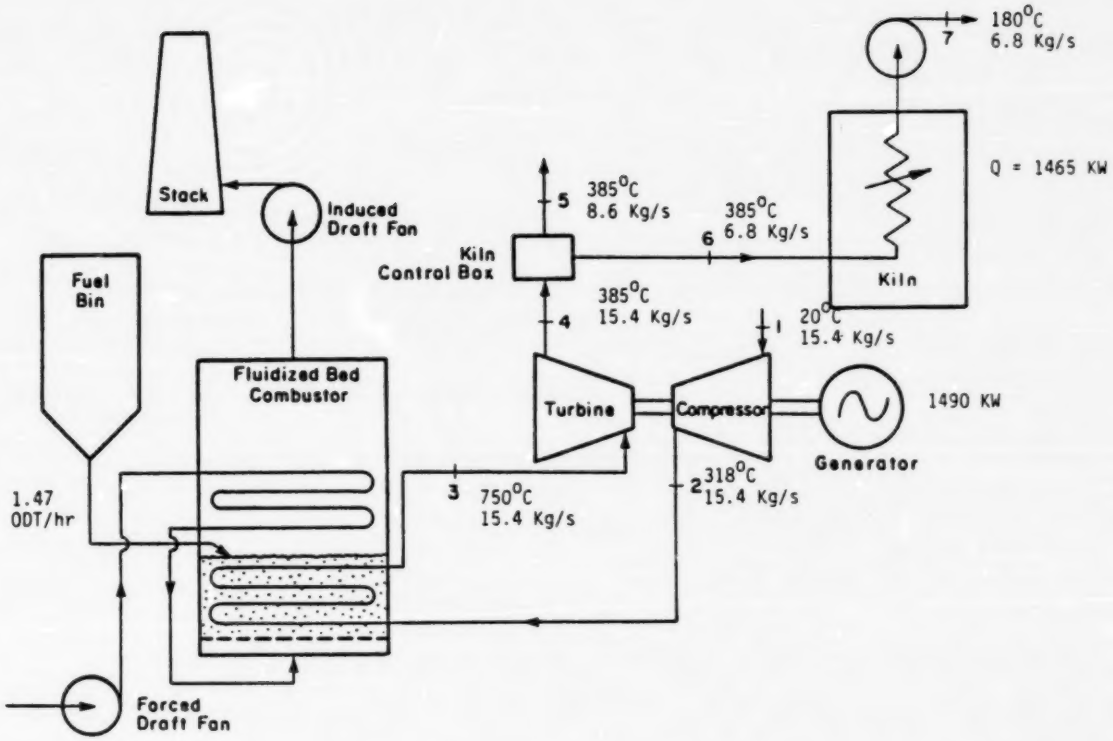

FIGURE 7: PART-LOAD HEAT BALANCE DIAGRAM
FOR DOUBLE TURBINE UNIT
100% ELECTRICAL LOAD, 50% KILN HEAT LOAD

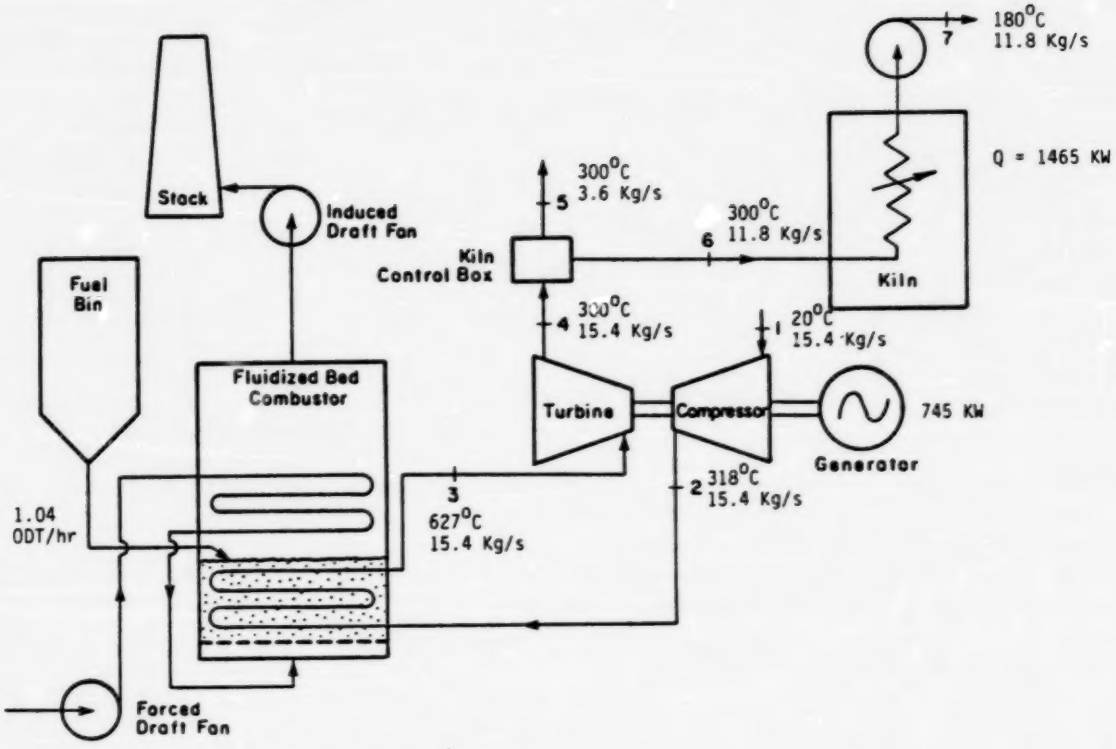

FIGURE 8: PART-LOAD HEAT BALANCE DIAGRAM
FOR DOUBLE TURBINE UNIT
50% ELECTRICAL LOAD, 50% KILN HEAT LOAD

bed temperature. This also reduces the turbine exit temperature compared to full-load operation, so the mass-flow rate to the kiln heat exchanger has to be increased compared to the previous case in order to maintain the kiln heat input of 1464 kW (5.3 GJ/hr). Because of the reduced bed temperature required, the fuel consumption is 1.04 ODT/hr, resulting in an overall thermal efficiency of 39 percent for the cogeneration system.

5.0 FINANCIAL ANALYSIS

This section presents estimates of capital and operating costs for the indirect-fired gas turbine cogeneration system and, based on these costs, analyzes the financial feasibility of the system under a variety of conditions.

5.1 Capital and Operating Cost Estimates

Table 5-1 details the estimated capital and operating costs for the 1340 kW system described in the previous section, along with those for a comparable 1340 kW steam system. The capital costs for both systems are specified on an installed basis. Capital cost of the fluid bed/gas turbine system is shown to be less than two-thirds that of the conventional steam system, while operating costs are estimated to be less than one-half those of the steam system. A major operating cost saving results from the lower labour requirements of the gas turbine system. It is expected to require only 2 hours of operating labour per shift, unlike the steam system which requires a full-time operator.

5.2 Financial Analysis Assumptions

A large number of variables must be considered when analyzing the financial feasibility of the cogeneration system examined herein. These include:

- the quantities of fuel and electricity displaced
- the cost of fuel and electricity displaced;
- future energy price escalation rates;
- whether or not surplus power can be sold to a utility or to a third party;
- debt/equity ratio;
- loan rate and amortization term;
- general inflation rate;
- possible changes in the capital cost.

TABLE 5-1: CAPITAL AND OPERATING COSTS OF FLUID BED/GAS TURBINE SYSTEM VERSUS CONVENTIONAL STEAM COGENERATION SYSTEM (1340 kW net)

FLUID BED/GAS TURBINE COGEN. SYSTEM		STEAM COGENERATION SYSTEM	
CAPITAL COST			
Fluid Bed Combustor	$1,230,000	Boiler plant & turbine	$3,216,000
Gas Turbine	$500,000	Fuel bin	$50,000
Fuel bin	$50,000	Conveyors	$25,000
Conveyors	$25,000	Heat exchangers (2)	$120,000
Heat exchangers (2)	$120,000	Switchgear and tie-in	$30,000
Ductwork, control box	$25,000	Engineering	$206,460
Controls	$20,000		
Building and sitework	$100,000		
Switchgear and tie-in	$30,000		
Engineering	$126,000		
TOTAL	$2,226,000	TOTAL	$3,647,460
OPERATING COST		OPERATING COST	
Maintenance	$55,650	Maintenance	$91,187
Operating labour	$40,000	Operating labour	$160,000
Ins. and Property taxes	$55,650	Ins. and Property taxes	$91,187
TOTAL	$151,300	TOTAL	$342,373

SOURCES OF COST ESTIMATES:

Gas turbine system:	
Capital and op. costs:	R.L. Evans and Bachrich Consulting Ltd.
- Engineering	6 % of capital costs.
- Maintenance	2.5 % of capital costs.
- Ins. and prop. taxes	2.5 % of capital costs.
- Labour	2 hours/shift, 4 shifts.
Conventional steam plant	
Capital costs for:	
- boiler and turbine	$2400/net kW based Table 5-8 of Volume IX of ENFOR Project C-258 (Simons Resource Consultants and B.H. Levelton & Associates Ltd., 1983).
- other components	Same basis as components in gas turbine system.
Operating costs:	
- maintenance, ins. and property taxes	Same percentage of capital costs as the gas turbine system.
- labour	One full-time steam engineer/shift @$40,000/annum times 4 shifts.

In order to facilitate analysis of the sensitivity of the cogeneration system to changes in these variables, a computer model incorporating all of these factors was developed to calculate the after-tax internal rate of return. Assumptions concerning these factors are discussed below:

Quantities of Fuel and Electricity Displaced

As noted in Section 4.0, the system can easily meet all kiln drying heat requirements, displacing 80,000 GJ of natural gas (or other purchased fuel) annually. Assuming full electrical output of 1340 kW for 3,840 hours/year, and 300 kW for another 4,560 hours/year when the kilns are the only major load, 6514 MW of electrical energy would be displaced along with 1340 kW of peak monthly demand.

In addition, the system is capable of producing a substantial quantity of high temperature waste heat, particularly during times when only the kilns are operating. Such heat could be used in a variety of applications if the sawmill located next to a plywood mill or pulp mill. For this analysis, however, it is conservatively assumed that only the mill's own purchased energy consumption is displaced by the system.

Fuel Prices

The predominant kiln-drying fossil fuel in Canadian sawmills is natural gas. Prices to sawmills in the interior of B.C. have dropped to about $3.50/GJ, including the 7 per cent provincial sales tax.

In mills east of Ontario, however, light and heavy fuel are the main kiln drying fuels, while liquified petroleum gases are used in mills in isolated parts of B.C. To represent these situations, therefore, three other base year fossil fuel prices are considered:

- $4.50/GJ for Ontario sawmills using natural gas;
- $4.50/GJ for Quebec sawmills using heavy fuel oil (price increased by 25% to allow for efficiency loss in heat exchanger);
- $7.50/GJ for mills using propane or butane in areas without access to gas service.

These prices are projected to escalate at the following real rates over the 20 year life of the project.

	Low Case	Base Case	High Case
Years 1 to 5	0%	0%	2%
Years 6 to 10	0%	2%	4%
Years 11 to 20	0%	4%	6%

Electricity Prices

The applicable interconnected grid electric rates for a sawmill of the scale considered herein are as follows:

	Demand Charge ($/kW/mo)	Energy Charge (cts/kWh)
B.C.	$6.01	2.64
Ontario	$4.60	3.44
Quebec	$3.93	2.23

Over the forecast period, the following electric rate escalation scenarios have been used in the financial analysis of the cogeneration system:

	Low Case	Base Case	High Case
Years 1 to 5	0%	0%	0%
Years 6 to 10	0%	1%	2%
Years 11 to 20	0%	1%	3%

A special case is also considered for mills in isolated areas where grid power is not available. The cost of diesel-electric generation in such areas is estimated to be approximately 15 cents/kWh, of which 10 cents/kWh would be fuel costs (B.C. Hydro and Power Authority 1984). This cost is escalated at the same rate as natural gas prices over the forecast period.

Utility Purchase of Surplus Electricity

At present the provincial electric utilities in B.C. and Quebec have a surplus of hydroelectric power; hence, they are not willing to purchase power from industry. This substantially reduces the potential for revenue generation by the system, as the sawmill can only displace 6,514 MWh of purchased power per annum versus a potential output of 9,391 MWh at 80 per cent capacity factor. In Ontario, however, the provincial utility will buy back power at a rate of 2.45 cents/kWh from private producers with a capacity factor of less than 65 percent.

Capital Cost

It should be appreciated that the capital cost estimates shown in Table 5-1 are preliminary estimates that need to be substantiated by a more detailed engineering design and cost study. As such, it seems prudent to examine the sensitivity of the internal rate of return to possible changes in the capital cost of the project. In this analysis capital cost variations of plus and minus 25 percent have been analysed relative to the base case.

Financial Assumptions

Based on discussions with chartered banks, the following conditions are considered to be a reasonable basis for project financing: 60/40 debt/equity ratio; 10-year loan amortization; 11 per cent interest rate. Other standard financial assumptions, as listed in Table 5-2, include project lifetime of 20 years, a corporate tax rate of 46% (for businesses with more than $200,000 taxable income), and a 4 per cent general inflation rate. The latter factor is applied to all parameters except the loan repayment which, of course, is fixed over the 20-year term.

TABLE 5-2: BASE CASE ASSUMPTIONS FOR ECONOMIC ANALYSIS*

CAPITAL AND OPERATING COSTS					
Capital Cost	$2,226,000				
Annual Operating Cost	$151,300				
REVENUE ASSUMPTIONS				Unit Cost	Annual Revenue (Year 0)
Natural gas displaced	(GJ)	80,000	$3.50	$/GJ	$280,000
Electricity cost savings:	Energy (Mwh)	6,514	$0.0264	$/kwh	$171,970
	Demand (kw)	1,340	$6.01	$/kw	$96,641
	Subtotal				$268,610
	TOTAL				$548,610
ENERGY PRICE ESCALATION	% per annum (real)				
Natural gas:					
Year 1 - 5	0%				
Year 6 - 10	2%				
Year 10 - 20	4%				
Electricity:					
Year 1 - 5	0%				
Year 6 - 10	1%				
Year 10 - 20	1%				
FINANCIAL ASSUMPTIONS					
Debt	60%				
Equity	40%				
Project Life	20	years			
Depreciation	3	years (25%, 50%, 25%)			
Investment tax credit	10%	of capital cost			
Tax Rate	46%				
General Inflation Rate	4%				
Loan rate	11%				
Loan term	10	years			

* Interior B.C. sawmill with access to natural gas and electricity.

This project qualifies for an accelerated depreciation allowance (25%, 50%, 25% over 3 years) under Class 34 of the Capital Cost Allowance system, which includes equipment used for the generation of electricity or the production or distribution of heat. In addition, an investment tax credit amounting to 10 per cent of the capital cost is available to sawmills in the northern B.C. interior and most other sawmilling areas of Ontario and Quebec. This credit is subtracted from the capital cost before calculating the allowable depreciation deductable from before-tax income.

The only financial assumptions varied in the sensitivity analysis are the debt/equity ratio and loan rate. While the 60/40 debt/equity ratio used in the base case analysis is considered to be a reasonable basis for financing a project of this nature, according to bank officials, the feasibility of the project is also presented on the basis of 100 percent equity to permit comparability with alternative investment opportunities evaluated on this basis. A 15 percent loan rate is used to represent a sensitivity case for higher risk borrowers.

5.3 Cases Considered in the Financial Analysis

The Base Case for this analysis is an interior B.C. sawmill that is currently using natural gas for kiln drying and purchasing electricity from the interconnected grid. With the current surplus of generating capacity in the province, it is assumed that the cogeneration facility only produces power for the sawmill's own needs. Table 5-2 lists the various assumptions underlying the Base Case analysis.

A variety of other cases representing different combinations of the foregoing variables have been considered, as specified in Table 5-3.

5.4 Financial Analysis Results

Table 5-3 presents the after-tax internal rates of return (IRR) calculated by the financial feasibility model for the Base Case and a number of sensitivity cases.

Case 1: British Columbia Location

TABLE 5-3: SUMMARY OF FINANCIAL ANALYSIS RESULTS FOR CASES CONSIDERED

CASE NO.	CASE DESCRIPTION	CHANGES TO BASE CASE ASSUMPTIONS IN TABLE 5.2	AFTER-TAX IRR
1	Base case*	None	38.4%
1a	No gas service	LPG used for kiln fuel @ $7.50/GJ	66.3%
1b	High capital cost	25% higher than base case	28.0%
1c	Low capital cost	25% lower than base case	50.1%
1d	Low energy price escalation	No real increase in energy prices over forecast period	37.5%
1e	High energy price escalation	Increases as detailed in Section 5.2	40.8%
1f	Higher risk borrower	15 % interest rate on project financing	35.8%
1g	Internal financing	100 % equity financing	20.1%
1h	Steam system	Conventional steam cogeneration system, Cap. and op. costs as in Table 5-1.	9.4%
2	Ontario location, no power sold	Ontario gas and electricity prices: Gas @ $4.50/GJ, elect. @ 3.44 cts/kWh, $4.60/kW/month demand charge	48.5%
2a	Ontario location, surplus power sold	Same as 2, but surplus power sold at 2.45 cents/kWh	54.7%
3	Quebec location	Quebec fuel oil and electricity prices: Fuel oil @ $4.50/GJ, elect. @ 2.23 cts/kWh, $3.93/kW/month demand charge	40.3%
4	Remote location	Nat. gas and grid power not available, LPG @ $7.50/GJ, electricity @ 15 cts/kWh	118.2%

* Interior British Columbia sawmill with access to natural gas and grid power. See Table 5-2 for Base Case Assumptions.

A very respectable after-tax rate of return of 38 percent is shown for the base case in Table 5-3; this improves to 66 percent for mills currently using LPG for kiln fuel (Case 1a). There are still a number of sizable sawmills in B.C. using LPG for kiln drying, and these mills would be a prime market for the gas turbine cogeneration system.

The financial analysis results also indicate that the IRR is moderately sensitive to variations in capital cost (Cases 1b and 1c). Even with a 25 percent increase, the system would provide an IRR of about 28 percent; a capital cost reduction of 25 percent would raise the IRR to more than 50 percent.

On the other hand, Cases 1d and 1e show that changes in rates of energy price escalation have an almost negligible impact on the rate of return. This is due, in part, to the assumption in all three price scenarios that there will be little or no increases in real energy prices during the next five years. Similarly, increasing the project financing cost to 15 percent (Case 1f) has only a small effect on the IRR.

In Case 1g, in which the project is financed on a 100 percent equity basis, the IRR drops to about 20 percent. Even this worst case, however, provides a better rate of return than the conventional steam cogeneration system (Case 1h) which shows less than a 10 percent rate of return, and a negative cash flow during some of the intermediate years of the project lifetime.

Case 2: Ontario Location

The base case IRR increase by about 10 percent, to more than 48 percent, for a sawmill located in Ontario (Case 2). This increase is primarily due to the higher natural gas prices in that province. If surplus power can be sold back to the utility, as is currently permitted in Ontario, the IRR increases to more than 54 percent. While such an increase would obviously enhance the viability of the system, Case 2a indicates that the ability to sell surplus power back to the utility is not critical to the financial feasibility of the system.

Case 3: Quebec Location

With lower electricity prices but higher fuel prices than in the base case, the overall rate of return (40 percent) is very similiar to that of the base case.

Case 4: Remote Location

Given the very high electricity and fuel prices typical of a remote location, this case exhibits an exceptionally attractive 118 percent IRR. While there are very few sawmills producing 50 million board feet per annum in such remote locations, this is partially due to the high cost of energy. The system considered herein could facilitate the establishment of new mills in previously-uneconomic areas and could be adapted to smaller mill scales. Therefore, although Case 4 is not a typical mainstream case, the gas turbine cogeneration system could prove very attractive to a limited number of existing sawmills and be incorporated into the design of new mills in remote areas.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Preliminary engineering work carried out during Phase I of this project has developed a design for an indirectly-fired gas turbine system that is capable of providing all of the kiln-drying heat requirements and most of the electrical requirements of a sawmill producing 50 million fbm of kiln-dried lumber. Sufficient wood residues are, in fact, available to generate all the mill's electrical requirements, but the extra generating capacity required may be more expensive than continuing to purchase a small amount of peak power from the utility. This matter will be further investigated during Phase II of the project when electric load patterns for one or more specific sawmills will be examined in detail.

The system proposed in this report is less complex and, on the basis of preliminary cost estimates, has much lower capital and operating costs than an equivalent capacity conventional steam-based cogeneration system. More detailed engineering design and costing for a specific site, however, will be required to provide definitive capital and operating cost estimates for the proposed system.

Given the preliminary cost estimates detailed in Table 5-1, however, the financial analysis shows that the system will provide an excellent internal rate of return, not only in the Base Case, but also in a variety of sensitivity cases. A number of sawmill industry officials contacted during the course of the study have expressed considerable interest in the proposed system.

On the basis of these expressions of interest, combined with strong indications that the system is both technically and financially feasible, the Study Team recommends that Phase II of the project should proceed as soon as possible. Phase II would be directed at achieving the following objectives:

- finding industrial participants and a site for building a demonstration project;

- carrying out a detailed engineering design and financial analysis for a specific site to the stage where a participation agreement can be put together for a demonstration project.

Successful achievement of Phase II objectives will allow Phase III of the project to proceed, in which an indirect-fired cogeneration system is built and operated on a demonstration site.

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